DEVELOPMENT OF CHITOSAN BASED ADSORBENT FOR THE REMOVAL OF RESIDUAL OIL FROM PALM OIL MILL EFFLUENT (POME)

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ABSTRACT

The focus of this research was to investigate and study the modified crosslinked chitosan beads as an adsorbent to adsorb the excessive residue oil from an oily wastewater. Palm oil mill effluent (POME) from the local palm oil mill was used as a sample of an oily wastewater. Raw chitosan present some limitations such as unsatisfactory mechanical properties, poor heat resistance and soluble in dilute acid aqueous solution. Crosslinking has been proposed in this study to overcome such weakness. Three types of crosslink agent, namely glutaraldehyde (GLA), ethylene glycol diglycidyl ether (EGDE) and epichlorohydrin (ECH) were used for this purpose. Series of batch adsorption experiments were carried out using different conditions and parameters. The controlled variables were adsorbent dosage, agitation rate, contact time and pH. A detailed batch study on chitosan flakes and the crosslinked chitosan beads with respect to its adsorption equilibrium, isotherm and kinetic study were also carried out. The best removal of residue oil was accomplished using chitosan flakes as adsorbent with adsorbent dosage of 15 g adsorbent per liter of POME, agitation rate of 100 rpm, contact time of 1 hr and pH of 6.0. Fourier transform infrared (FTIR) spectrophotometer and scanning electron microscope (SEM) images of chitosan flakes and crosslinked chitosan beads before and after the adsorption experiments were presented to prove that the residue oil had been adsorbed by these adsorbents. The Langmuir isotherm model provided the best fit for the equilibrium data in the concentration range investigated, with the maximum adsorption capacity being 131.58 mg of residue oil per gram of chitosan flakes, as obtained from the linear equation of the isotherm. The adsorption kinetics was tested using three models: pseudo-first-order, pseudo-second-order and intraparticle diffusion model. The experimental kinetics data were properly correlated with the pseudo-second-order kinetic model (R^2=0.9996), which provided a rate constant, k_2, of 0.0021 g/mg.min. The research study had attested chitosan and crosslinked chitosan beads as a potential adsorbent to adsorb residue oil from POME.

ABSTRAK

Fokus penyelidikan ini adalah untuk menyiasat dan menkaji pengubahsuaian rangkaisilang manik kitosan sebagai penjerap untuk menjerap lebihan minyak sisa daripada air sisa berminyak. Air kumbahan kilang kelapa sawit (POME) dari kilang kelapa sawit tempatan telah dikenalpasti sebagai sampel air sisa berminyak. Kitosan asal mempunyai beberapa batasan seperti ketidakpuasan ciri-ciri mekanikal, penahanan haba yang lemah dan larut dalam larutan akues asid. Rangkaisilang telah dicadangkan dalam kajian ini untuk menangani kelemahan tersebut. Tiga jenis ejen rangkaisilang, dinamakan glutaraldehid (GLA), etilin glikol diglisidil eter (EGDE) dan epiklorohidrin (ECH) telah digunakan untuk tujuan ini. Siri eksperimen penjerapan telah dijalankan menggunakan keadaan dan parameter berbeza. Pembolehubah kawalan adalah dos penjerap, kadar pusingan, masa pencampuran dan pH. Satu kajian terperinci terhadap empingan kitosan dan manik kitosan berangkaisilang dengan merujuk kepada kajian keseimbangan penjerapan, garis sesuhu dan kinetik juga dilakukan. Penyingkiran terbaik minyak sisa adalah dicapai menggunakan empingan kitosan sebagai penjerap dengan dos penjerap 15 g penjerap per liter POME, 100 rpm kadar pusingan, 1 jam masa pencampuran dan pH 6.0. Spektrofotometer inframerah pengubah Fourier (FTIR) dan imej mikroskop elektron pengimbas (SEM) empingan kitosan dan manik kitosan berangkaisilang sebelum dan selepas eksperimen penjerapan telah disediakan untuk membuktikan bahawa minyak sisa telah dijerap oleh penjerap-penjerap tersebut. Model garis sesuhu Langmuir menyediakan muat terbaik bagi data keseimbangan dalam lingkungan kepekatan yang disiasat, dengan muatan penjerapan maksimum adalah 131.58 mg minyak sisa per gram empingan kitosan, seperti yang didapati daripada persamaan lurus garis sesuhu. Kinetik penjerapan diuji menggunakan tiga model: “pseudo-first-order”, “pseudo-second-order” dan model penembusan intrazarah. Data eksperimen kinetik berhubung baik dengan modek kinetic “pseudo-second-order” (R^2 = 0.9996), yang menyediakan kadar tetap, k_2, adalah 0.0021 g/mg.min. Kajian penyelidikan ini telah menguji kitosan dan manik kitosan berangkaisilang sebagai potensi alternatif untuk menjerap minyak sisa daripada POME.

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LIST OF SYMBOLS

c_i	Concentration of adsorbate in solution for linear isotherm
C_e	Equilibrium adsorbate concentration in solution
C_o	Initial adsorbate concentration in solution
k_i	Intraparticle diffusion rate constant
k_1	Pseudo-first-order rate constant
k_2	Pseudo-second-order rate constant
K_i	Adsorption constant for linear isotherm
K_F	Freundlich constant related to adsorption capacity
K_L	Langmuir adsorption constant related to the affinity of binding sites
m	Mass of adsorbent
N	Avogadro's number
n	Freundlich constant related to adsorption intensity
n_i	Concentration of adsorbate in adsorbent for linear isotherm
q_e	Amount of adsorbate adsorbed at equilibrium
q_m	Maximum adsorption capacity corresponding to complete monolayer coverage
q_t	Amount of adsorbate adsorbed at time t
R^2	Correlation coefficient
R_L	Separation factor, dimensionless constant
s	Adsorption cross section
S	Specific surface area
S_{total}	Total surface area
t	Time taken for adsorption
V	Sample volume

LIST OF ABBREVIATIONS

APHA	American Public Health Association
BET	Brunauer, Emmett, and Teller
BOD	Biochemical oxygen demand
CPO	Crude palm oil
DA	Deacetylation
DC	Decoloration
DM	Demineralization
DOE	Department of Environment
DP	Deproteinization
ECH	Epichlorohydrin
EGDE	Ethylene glycol diglycidyl ether
EQA	Environmental Quality Act
FFB	Fresh fruit bunches
FTIR	Fourier Transform Infrared
GLA	Glutaraldehyde
GRAS	General Recognized as Safe
HRT	Hydraulic retention time
IUPAC	International Union of Pure and Applied Chemistry
MRE	Mixed raw effluent
O&G	Oil and grease
POME	Palm oil mill effluent
SEM	Scanning electron microscopy
US FDA	United Stated Food and Drug Administration

CHAPTER 1

INTRODUCTION

1.1 CHITOSAN AS BIOSORBENT IN WASTEWATER TREATMENT

Application of chitinous products in wastewater treatment has received considerable attention in recent years in the literature. In particular, the development of chitosan-based materials as useful adsorbent is an expanding field in the area of adsorption science (Crini and Badot, 2008)

It is now recognized that adsorption using low-cost adsorbent is an effective and economic method for water decontamination. A large variety of non-conventional adsorbents have been proposed and studied for their ability to remove pollutant or contaminant from wastewater. However, low-cost adsorbents with high adsorption capacities are still under development to reduce the adsorbent dose and minimize disposal problems. Much attention has recently been focused on various biosorbent materials such as fungal or bacterial biomass and biopolymers that can be obtained in large quantities and that are harmless to nature. Special attention has been given to polysaccharides such as chitosan, a natural aminopolymer.

Chitosan has been investigated by several researchers as a biosorbent for the capture of some pollutant such as oil and grease, heavy metals, dissolved dyes and other toxic substances from wastewater. This natural polymer possesses several intrinsic characteristics that make it an effective biosorbent. Its use as a biosorbent is justified by two important advantages: firstly, its low cost compared to commercial activated carbon (chitosan is derived by deacetylation of the naturally occurring biopolymer chitin which is the second most abundant polysaccharide in the world

after cellulose); secondly, its outstanding chelation behavior (one of the major applications of this aminopolymer is based on its ability to tightly bind pollutants, in particular heavy metal ions).

1.2 WHY CHITOSAN?

The majority of commercial polymers and ion-exchange resins are derived from petroleum-based raw materials using chemistry that is not always safe or environmental friendly. Today, there is growing interest in developing natural low-cost alternatives to synthetic polymers (Crini, 2006).

Chitin, found in the exoskeleton of crustaceans, the cuticles of insects, and the cells walls of fungi is the most abundant aminopolysaccharide in nature (Synowiecki and Al-Khateeb, 2003; Rinaudo, 2006). This low-cost material is a linear homopolymer composed of β(1-4)-linked *N*-acetyl glucosamine. It is structurally similar to cellulose, but it is an aminopolymer and has acetamide groups at the C-2 positions in place of the hydroxyl groups. Figure 1.1 shows the different chemical structure between chitin and cellulose. The presence of these groups is highly advantageous, providing distinctive adsorption function and conducting modification reactions. The raw polymer is only commercially extracted from marine crustaceans primarily because a large amount of waste is available as a by-product of seafood processing industry (Synowiecki and Al-Khateeb, 2003).

Since the biodegradation of chitin is very slow in crustacean shell waste, accumulation of large quantities of discards from processing of crustaceans has become major concern in the seafood processing industry. Therefore, there is a need to recycle these by-products. Their use for the treatment of wastewater from another industry could be helpful not only to the environment in solving the solid waste disposal problem, but also to the economy. However, chitin is an insoluble material. Its insolubility is a major problem that confronts the development of processes and uses of chitin (Rinaudo, 2006), and so far, very few large-scale industrial uses have been found. More important than chitin is its derivative, chitosan.

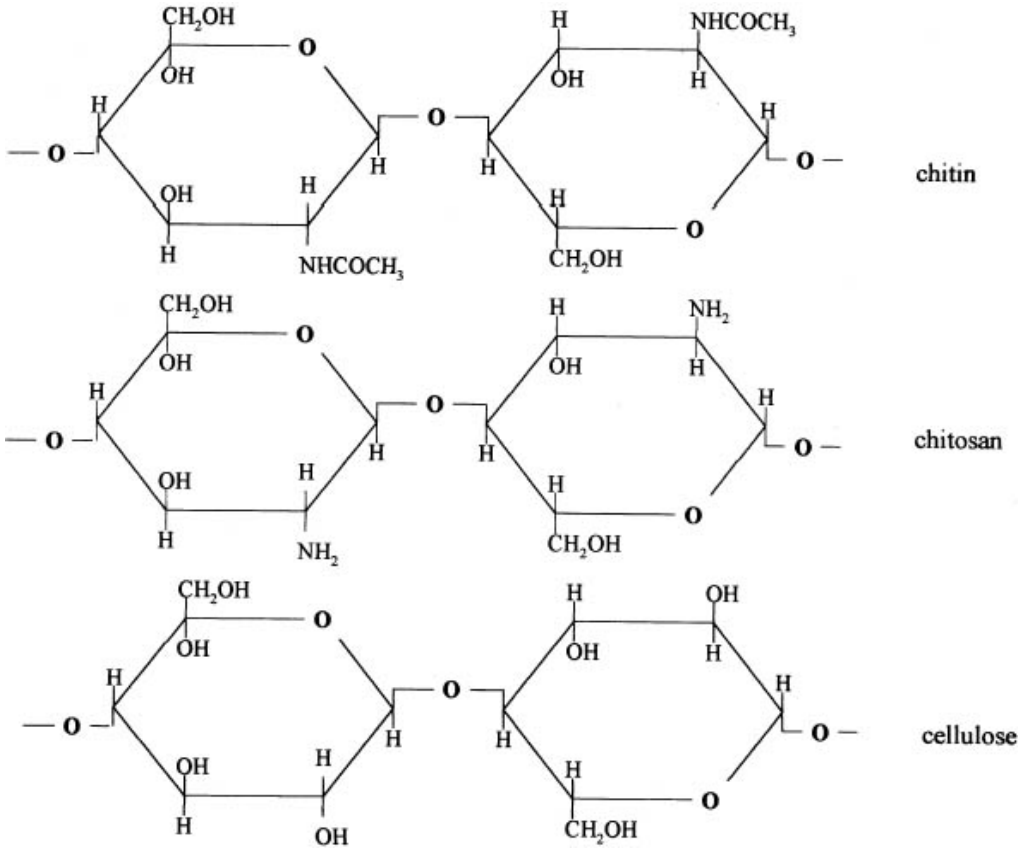

Figure 1.1: Chemical structures of chitin, chitosan and cellulose

Source: Ravi Kumar (2000)

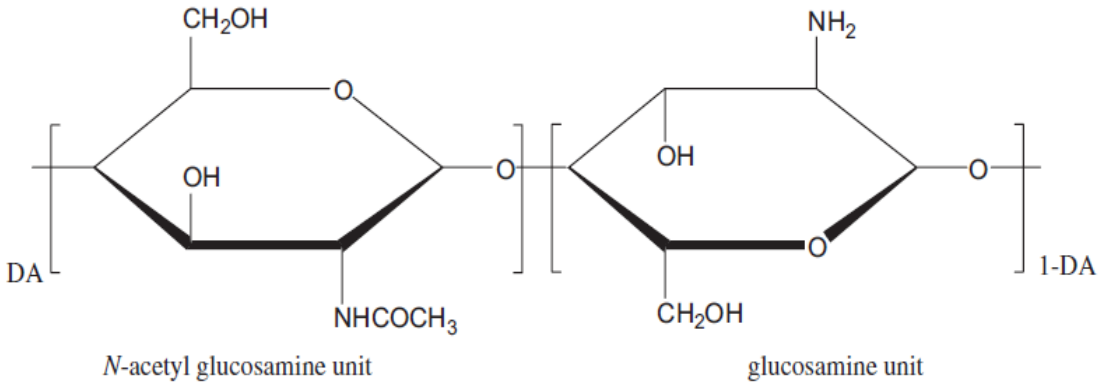

Figure 1.2: Commercial chitosan (a copolymer characterized by its average degree of deacetylation (DA)

Source: Crini and Badot (2008)

Partial deacetylation of chitin results in the production of chitosan, which is a polysaccharide composed by polymers of glucosamine and N-acetyl glucosamine (Figure 1.2). The “chitosan label” generally corresponds to polymers with less than 25 % acetyl content. The fully deacetylated product is rarely obtained due to the risks of side reactions and chain depolymerization. Copolymers with various extents of deacetylation and grades are now commercially available. Chitosan and chitin are of commercial interest due to their high percentage of nitrogen compared to synthetically substituted cellulose.

Chitosan is soluble in acid solutions and is chemically more versatile than chitin or cellulose. The main reasons for this are undoubtedly its appealing intrinsic properties, as documented in a recent review (Rinaudo, 2006), such as biodegradability, biocompatibility, film-forming ability, bioadhesivity, polyfunctionality, hydrophilicity and adsorption properties. Most of the properties of chitosan can be related to its cationic nature (Peter, 1995; Struszczyk, 2002; Synowiecki and Al-Khateeb, 2003; Rinaudo, 2006), which is unique among abundant polysaccharides and natural polymers. These numerous properties lead to the recognition of this polyamine as a promising raw material for adsorption purposes.

1.3 RESEARCH BACKGROUND

Many industries such as vegetable oil processing industry, foods and beverages, dairies and slaughterhouses, and metal products and machinery industry normally discharge large volumes of oily wastewater (Mueller *et. al.*, 1997; Faisal and Unno, 2001; Azbar and Yonar, 2004; Cammarota and Freire, 2006; Nardi *et. al.*, 2008). The presence of high strength oil and grease (O&G) in industrial wastewaters poses serious challenges for biological treatment systems (aerobic and anaerobic), often necessitating costly modifications by inclusion of physio-chemical processes such as flotation, sedimentation, flocculation and membrane filtration (Barnes *et. al.*, 1984; Nakhla *et. al.*, 2003).

Reducing the environmental loading from oily wastewater, decreasing processing costs and other products that utilize residue are strong drives for oily wastewater treatments (Andrew *et. al.*, 2000). A large number of pretreatment systems employed to remove O&G to prevent a host of problems that may otherwise arise in the biological process, and reduce the efficiency of the treatment station. Problems caused by excessive O&G include a reduction in the cell-aqueous phase transfer rates, a sedimentation hindrance due to the development of filamentous microorganisms, development and flotation of sludge with poor activity, clogging and the emergence of unpleasant odors. Therefore, the application of a pretreatment to hydrolyze and dissolve lipids may improve the biological degradation of oily wastewaters, accelerating the process and improving time efficiency (Cammarota and Freire, 2006).

Adsorption techniques are widely used to remove certain classes of pollutants from wastewaters, especially those that are not easily biodegradable (Crini, 2006). However thus far, only few studies describing the treatment of oily wastewater by adsorption process have been reported. With the increasing demand for economic large-scale water treatment applications, the development of novel, low-cost, stable and efficient sorbent, therefore, is of great significance (Li *et. al.*, 2007).

Recently, numerous approaches have been studied for the development of cheaper and more effective adsorbent. Many non-conventional low-cost adsorbents, including natural materials, biosorbents, and waste materials from industry and agriculture, have been proposed by several works (Crini, 2006). Currently, biopolymers are industrially attractive because they are widely available and environmentally safe. Amongst them, chitosan remains special attentions as a natural polysaccharide. Chitosan is the second most abundant biopolymer in the nature and waste product of seafood processing industries. It is a natural polymer derived from chitin, a polysaccharide found in the exoskeleton of shellfish like shrimp or crabs. Chitosan made up of a linear polycationic polymer that contains 2-acetamido-2-deoxy-β-D-glucopyranose residues (Wan Ngah *et. al.*, 2008). It has been used in several sorts of wastewaters treatment, but less in oily wastewater treatment.

Raw chitosan tend to present some disadvantages such as unsatisfactory mechanical properties and poor heat resistance. Another important limitation of the raw materials is that it is soluble in acidic media and therefore cannot be used as an insoluble adsorbent under these conditions, except after physical and chemical modification. One method to overcome these problems is to transform the raw polymer into a form whose physical characteristics are more attractive. Therefore, crosslinked chitosan beads have been developed and proposed. After crosslinking, these materials maintain their properties and original characteristics (Cestari *et. al.*, 2004), particularly their high adsorption capacity, although this chemical modification results in a decrease in the density of free amine groups at the surface of the adsorbent in turn lowering polymer reactivity towards metal ions (Gibbs *et. al.*, 2004).

Different kinds of crosslinking agents such as glutaraldehyde (Chiou and Li, 2003; Wan Ngah *et. al.*, 2005, 2008), epichlorohydrin (Chiou and Li, 2003; Cestari *et. al.*, 2004; Chiou *et. al.*, 2004; Wan Ngah *et. al.*, 2005) and ethylene glycol diglycidyl ether (Wan Ngah *et. al.*, 2002, 2005; Chiou and Li, 2003) have been used in crosslinking of chitosan beads. This study was mainly aimed to investigate the performance of efficiency of crosslinked chitosan beads for the removal of oil from industrial wastewater. Palm oil mill effluent has been chosen as the sample of oily wastewater to evaluate the effectiveness of the biosorbent in wastewater treatment.

1.4 OBJECTIVES

In the present research, the effectiveness of crosslinked chitosan beads as adsorbent in removing the residue oil from POME was examined and analyzed. The results were compared with the native chitosan flakes. The aims of this research were focused to:

(i) Synthesize and characterize the crosslinked chitosan beads using three different crosslinking agents, which are glutaraldehyde (GLA), epichlorohydrin (ECH) and ethylene glycol diglycidyl ether (EGDE).

(ii) Study the adsorption of residue oil from POME on chitosan flakes and three different crosslinked chitosan beads under various parameters and optimize the best adsorption condition in a batch system. Experiments were carried out as a function of adsorbent dosage, pH of solution, contact time and agitation rate.

(iii) Study the equilibrium isotherms based on Langmuir and Freundlich isotherm equation model and determine the adsorption constant for both isotherm tested.

(iv) Study the kinetics of adsorption with respect to the initial residue oil concentration. The pseudo-first-order, second-order kinetic models and intraparticle diffusion model will be use to describe the kinetic data and evaluate the rate constant for all model.

1.5 RESEARCH SCOPES

In order to achieve the objectives of this research, several scopes have been identified.

(i) Analyzing the surface morphology of chitosan flakes and crosslinked chitosan beads before and after the adsorption process. Scanning electron microscopy was used for this purpose.

(ii) Analyzing the functional groups of each adsorbent that might be involved in residue oil adsorption which performed using Fourier Transform Infrared (FTIR) spectrophotometer.

(iii) Obtaining the optimum conditions (weight dosage, pH, contact time and agitation rate) for the adsorption of residue oil from POME for each type of adsorbents. The batch adsorption experiments were conducted using a conventional jar apparatus (Phipps & Bird PB-700 Jartester

model) which can accommodate six beakers and can be simultaneously stirred at the same speed with six-spindle of steel paddles.

(iv) Adsorption equilibrium isotherm studies were conducted using the optimized conditions (weight dosage, pH, contact time and agitation rate) for all types of adsorbent.

(v) Kinetics of adsorption studies were conducted using the optimized conditions (weight dosage, pH, contact time and agitation rate) for all types of adsorbent.

CHAPTER 2

LITERATURE REVIEW

2.1 PALM OIL PROCESSING INDUSTRY

Back in 1962, the annual production of world palm oil was reported only 1.23 million tons. Today, palm oil is the second largest produced oil after soybean oil with a production level of 29.8 million tons (Malaysian Palm Oil Board). The four-decade performance of world palm oil is commendable and it is envisaged that this record of accomplishment will continue into the future. According to Basiron and Simeh (2005), towards 2020, it will continue to be the world largest edible oil produced with a production of 43.3 million tons, which is an increase of 50 % from the present. Currently, Malaysia is the largest palm oil producer and forecasted to maintain its lead position over the next decades with contribution of 18 million tons or 42 % of the world palm oil production in 2020. With increased cultivation and production of palm oil in the region, the disposal of the processing waste is becoming a major problem that must be appropriately addressed.

The extraction process for crude palm oil (CPO) starts from the local palm oil mills throughout Malaysia. The mills processes fresh fruit bunches (FFB) received from the oil palm plantations into CPO and other by-products. It is important to note that no chemicals are added in the extraction of oil from the oil palm fruits, therefore making all generated waste nontoxic to the environment (Hassan et al., 2006). The extraction of CPO involves mainly mechanical and heating processes, and is illustrated in several steps shown in Figure 2.1.

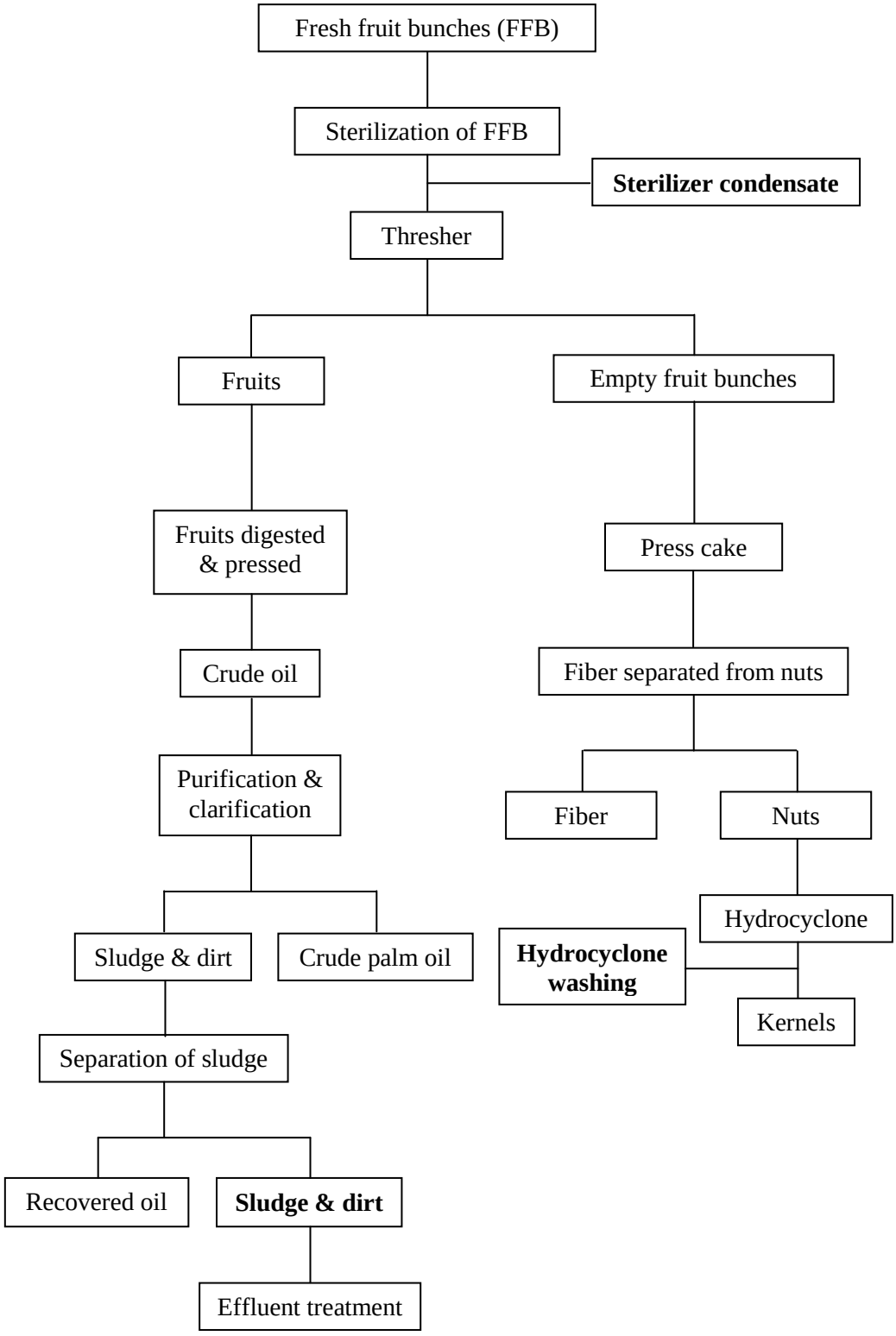

Figure 2.1: Flow diagram of CPO extraction processes and source of POME

Source: Hassan et al. (2006)

The environmental issues of the CPO industry are primarily related to numerous factors such as:

(i) Water pollution due to indiscriminate discharge of untreated or partially treated palm oil mill effluents into public watercourses;

(ii) Improper interim storage of solid waste materials including boiler and incinerator ash, decanter solids, spent bleaching earth and sludge separator residue;

(iii) Improper land-application techniques or practices for solid and/or liquid wastes;

(iv) Air pollution due to the use of solid fuel fired boilers for empty bunches;

(v) Odor emission from poorly managed effluent treatment systems, especially, if they are located in close proximity to neighboring residential areas; and

(vi) Noise from the milling processes.

Palm oil mills are traditionally located near rivers from which water is abstracted for their milling operations. A number of palm oil mills conveniently discharged their treated effluents into the river in an untreated or partially treated condition, as this was the cheapest method of POME disposal since POME was a non-toxic oily waste. Certain beneficial effects may have been initially derived due to available nutrients and enhanced growth of micro-plankton, which is an essential food for aquatic life. However, excessive quantities of untreated POME deplete a water body of its oxygen and suffocate the aquatic life. Thus, the impact of raw POME discharge to a relatively small river can be devastating to its eco-system and beneficial uses. The advent of strict environment regulations has made the palm oil proprietor to realize the eco-concern and learnt to treat the waste into an environmental friendly waste.

2.2 PALM OIL MILL EFFLUENT (POME)

Palm oil mill and palm oil refineries are two main sources of POME. An estimated 30 million tons of POME are produced annually from more than 300 palm oil mills in Malaysia (Hassan et al., 2006). POME originates from two main processes: sterilization and clarification stages, as the condensate and clarification sludge, respectively (Figure 2.1). The clarification sludge shows higher level of solid residues compared to the sterilizer condensate. Both contain some level of unrecovered oils and fats. The final POME would of course include hydrocyclone washing and cleaning up processes in the mill (Agamuthu, 1995). Approximately 1-1.5 tons of water are required to process 1 ton of FFB. The volume of the combined POME discharged depends largely on the milling operations (Gurmit et al., 1999).

2.2.1 Characteristics of POME

Based on the process of oil extraction and the properties of FFB, POME is made up of about 95-96 % of water, 0.6-0.7 % of oil and 4-5 % total solids, including 2-4 % suspended solids, which are mainly debris from palm mesocarp (Ma, 1999, 2000). No chemicals are added during the production of palm oil; thus, it is a nontoxic waste. Upon discharge from the mill, POME is in the form of highly concentrated dark brown colloidal slurry of water, oil and fine cellulosic materials. Due to the introduction of heat (from the sterilization stage) and vigorous mechanical processes, the discharge temperature of POME is approximately 80-90 ºC with pH ranging from 4.0-5.0. The characteristics of POME vary widely and depend on the operation and quality control of individual mills (Basiron and Darus, 1995). The general characteristics of POME are indicated in Table 2.1.

Apart from the organic composition, POME is also rich in mineral content, particularly phosphorus, potassium, magnesium and calcium (Ma, 1999). Thus, most of the dewatered POME dried sludge (the solid end-product of the POME treatment system) can be recycled or return to the plantation as fertilizer.

Table 2.1: Characteristics of palm oil mill effluent (POME)

Parameters	Average	Range	Elements	Average
pH	4.2	3.4-5.2	Phosphorus	180
Oil and grease	6 000	150-18 000	Potassium	2 270
BOD	25 000	10 000-44 000	Magnesium	615
COD	50 000	16 000-100 000	Boron	7.6
Suspended solid	40 500	11 500-79 000	Iron	47
Dissolved solids	18 000	5 000-54 000	Manganese	2.0
Ammonical nitrogen	35	4-80	Calcium	440
Total nitrogen	750	80-1 400	Zinc	2.3

*All units are in mg/L except for pH

Source: Malaysian Palm Oil Board (1999)

2.2.2 Pollution Load and Effect of Discharge

The production of CPO in 2003 increased markedly by 12.1 % or 1.4 million tons to 13.35 million tons from 11.91 million tons in 2002 (Malaysian Palm Oil Board, 2004) which is about 46 000 m^3 per day. Based on this quantity of daily CPO production, the total quantity of effluent generated per day can be averaged up to 161 000 m^3 and the total BOD_3 load of raw effluent generated per day is about 4025 tons. Finally the population-equivalent of raw effluent BOD_3 load (at 0.05 kg BOD / Capita / Day) is equal to 64 000 000 persons. This pollution statistics indicate that if the entire palm oil industry discharges raw effluent, then the total pollution load of the industry would be equivalent to that of a POME when discharged untreated or partially treated into the river stream undergoes natural decomposition during which the dissolved oxygen of the river or stream is rapidly depleted (Gurmit, 1999).

The palm oil present in the effluent may float to the surface of the water body and form a widespread film which can efficiently cut-off and avert atmospheric oxygen from dissolving into its waters. Furthermore, when the organic load far exceeds its waste assimilation capacity, the available oxygen in the water body is rapidly consumed because of the natural biochemical processes that take place. The water body may become completely devoid of dissolved oxygen. This will lead to anaerobic conditions in which hydrogen sulphide and other malodorous gases are

generated and released to the environment resulting in objectionable odors. Additional damaging effects include the decline and eventual destruction of aquatic life and deterioration in the river eco-system.

Moreover it is predicted that, the Malaysian oil palm industry in 2004 to remain bullish. The production of CPO is projected to increase by 2.3 % to 13.66 million tons (Malaysian Palm Oil Board, 2004). Hence serious measures have to be taken in order to prevent the growing pollution caused by POME.

2.2.3 Regulatory Control of Effluent Discharge

Oil palm cultivation and processing are regulated by a number of environmental legislations aimed at conserving and protecting the natural environment. These rules and regulations, together with the growing awareness for a clean and pollution-free environment play a significant role in minimizing the degradation of the soil, water and atmospheric environment. The Malaysian Department of Environment (DOE) being the government agency acted responsibility in enacting the Environmental Quality Act (EQA) in 1974 and specific regulations for palm oil mill effluent in 1977.

EQA is an enabling act aimed to prevent, abate and control pollution for the protection of public health and the environment. The highlighting agenda of EQA was to set acceptable standards for the emission and discharge or deposits of pollutants into the environment rather than prevention, with an exception given to the necessities on environmental impact measurements. Environmental Quality (Prescribed Premises) (Crude Palm Oil) Regulations 1977 were promulgated under the Section 51 Environment Quality Act 1974 for environmental control of palm oil mills discharge. Table 2.2 represents the current effluent discharge standards ordinarily applicable to the crude palm oil mills. Therefore the palm oil millers have to encompass proper pollution control practices to fulfill the discharge limits set by the DOE (Md. Noor, 1974).